THE VESTIBULAR SYSTEM'S INFLUENCE ON THE PERCIVED DURATION OF LIGHT, SOUND, AND TOUCH

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A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE GRADUATE PROGRAM IN BIOLOGY YORK UNIVERSITY

GRADUATE PROGRAM IN BIOLOGY,
YORK UNIVERSITY
TORONTO, ONTARIO

June 2025

Abstract

Time perception is fundamental yet influenced by many factors, including gravity. While microgravity alters time perception (Navarro Morales et al., 2023), isolating gravity's role remains difficult. To probe this, I manipulated vestibular input by comparing participants' time perception while standing versus supine. Participants (n=124) judged whether stimuli lasted longer or shorter than one second across four experiments: visual (LED light), auditory (200 Hz tone), tactile (200 Hz vibration), and visual with/without disruptive galvanic vestibular stimulation (dGVS). Results showed that visual and tactile stimuli were perceived as longer than auditory ones. Auditory and tactile duration judgments were unaffected by posture, but visual time perception was significantly lengthened when supine (by 45ms) or during dGVS (by 66ms). These findings suggest that the vestibular system specifically modulates visual time perception. When vestibular signals are disrupted—by lying down or electrical stimulation—visual time appears to slow, highlighting a sensory-specific interaction between balance and temporal perception.

Acknowledgements

I want to thank Dr. Laurence Harris for his mentorship and support throughout my studies. I would also like to thank Dr. Laurie Wilcox for her sound scientific advice and Björn Jörges for his enthusiasm and assistance in data collection,

An Ontario Graduate Scholarship, a VISTA Scholarship and a CVR CREATE stipend funded this research. I would like to thank the funding agencies responsible for making my research possible. Finally, I would like to thank the other members of the Multisensory Integration Lab for their continued support of my research, both as academic peers and as friends.

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Introduction:

Time perception is a crucial aspect of human life and experience. The ability to gauge the timing of events, assess their durations, and determine their sequence is essential to making decisions, evaluating outcomes, and making informed decisions. However, the subjective experience of an event's duration and actual, measurable time can be influenced by several external factors, including the stimulus type (Grommet et al., 2011), the strength of the sensory signal (Wearden et al., 2007), and other factors. My study explicitly examines vestibular stimulation's influence on time perception, a relatively underexplored area. Auditory and visual stimuli have been used most when investigating duration perception. (Bueti et al., 2008). Since the 19th century, it has been known that the durations of auditory and visual stimuli are usually perceived to be different, even when the stimuli last the same length of time (Wearden et al., 2006). Durations are judged to be longer when markers indicating the beginning and end of a period being judged are auditory rather than when they are visual (Bueti et al., 2008). Khoshnoodi et al. (2008) investigated the effect of vibrotactile stimuli on time perception. They showed that subjects overestimated the duration of a period marked by tactile stimuli as a function of test stimulus frequency. Therefore, my research further investigated the differences that stimulus type makes in time duration.

I used perceptual estimates of 1 second in this thesis as I was primarily interested in the effect of vestibular stimulation on the perceived duration of different stimuli. In the "future directions" section, I discuss why longer periods might be interesting and the challenges of using longer periods in a robust psychophysical paradigm. Studies have shown that the accuracy of time perception varies depending on the duration estimated. For example, when durations are

around 1 to 3 seconds, typically within the scope of short-term sensory memory, time estimation is more accurate than it is for longer periods (Droit-Volet & Hallez, 2019).

Vestibular system and time perception

The vestibular system, responsible for detecting the acceleration of the head, both self-generated and from gravity, provides us with information regarding our position and orientation in space and contributes to a sensation of self-motion (Angelaki & Cullen, 2008). Accelerations can come from self-motion—either active (e.g., walking) or passive (e.g., being in a car) — or from the acceleration of gravity (e.g., falling). The cerebellum, the subcortical brain structure primarily responsible for motor coordination and the vestibular control of balance (Merchant et al., 2013) has also been implicated in timing functions. Patients with damage to the cerebellum were more variable and less accurate in producing rhythmic finger tapping and had poorer performance in duration discrimination tasks (Utegaliyev et al., 2022). This implies that damage to the vestibular system (which the cerebellum processes) could lead to time perception interruptions or distortions (Israël et al., 2004).

Only a few studies have investigated the effect of vestibular stimulation on temporal judgments. Most research has focused on gravity's effect (an acceleration the vestibular system is sensitive to) on time perception. One of the earlier studies on this topic exposed subjects to "gravitational stress". Subjects were seated in a cabin at the end of a centrifuge arm. They had to reproduce temporal intervals of auditory tones between 1 and 20 seconds by pressing and releasing a button whilst being spun at various speeds on the centrifuge. The reproduced intervals fell short of the stimulus durations when measured in the 1g control condition. However,

judgments of the duration of 1s were even shorter under the gravitational stress (2g) induced by centrifugation (Era et al., 2006).

A more recent study (Navarro Morales et al., 2023) considered the effect of gravity on the vestibular system and time perception. They compared the time estimation of astronauts on board the International Space Station (ISS) with control measures taken on the Earth. In contrast to the gravitational stress the centrifuge applies, being on the ISS cancels gravity, producing essentially 0g. Their results showed that astronauts on board the ISS perceived the duration of time differently than on Earth. They indicated a 1-minute interval by pressing a button. Before the flight, the subjects judged a minute as an average of 74.1 seconds. In other words, at the clock time of 60s, the subjects still thought perhaps only 50s had passed and waited longer before pressing the button. The relative underestimation when on the ISS by the astronauts of around 60s compared to around 75s on Earth, indicates a relative overestimation of duration when exposed to the microgravity of space. In other words, astronauts in space feel that more time has gone by after 60s than when on the ground.

In addition to adding to and removing the physical linear acceleration of gravity, changing the body's posture shifts the direction in which the gravitational vector affects the vestibular system (Chung & Barnett-Cowan, 2023). We are used to being upright in our regular standing or sitting posture. However, lying on our backs stimulates the vestibular system unusually. Its signal is less reliable and noisier under these circumstances. For example (Hummel et al., 2016) showed that vestibular heading perception was strongly modified in a supine position (while participants were lying down on a moving platform), while other factors investigated in their studies, like visual performance, did not change. It has also been proven that

our estimation of heading direction is affected by posture (MacNeilage et al., 2010). They also found that both vestibular and visual directional sensitivity was best when upright. This shows that the nervous system is specialized to operate efficiently in our most-commonly-experienced orientation. Therefore, as posture affects the vestibular system and the vestibular system affects time perception, logically, posture should affect duration perception. Moreover, the overlap in the brain regions involved in temporal perception and those involved in the vestibular system (the insular cortex-frontal and parietal, basal ganglia, cerebellum, and hippocampus, Fontes et al., 2016; Marcelli et al., 2009) further suggests that postural change might affect time perception. This thesis investigates the influence of the vestibular system on the perceived duration of visual, tactile, and auditory stimuli.

Galvanic Vestibular Stimulation

In addition to natural stimulation provided by acceleration, studies show that Galvanic Vestibular Stimulation (GVS) using transcutaneous electrical stimuli to activate the vestibular apparatus is an easy-to-use and relatively safe method for neuroscientific research requiring stimulating the vestibular system. The vestibular system can be artificially stimulated by electricity, taking advantage of its proximity to the surface of the skull (Utz et al., 2010). GVS has been used for over a century to discover and examine the vestibular system's function (e.g., Fitzpatrick & Day, 2004). Galvanic vestibular stimulation (GVS) upsets balance and equilibrium and can mimic the natural activity of the vestibular system (Kim, 2013). Initial research simulated the natural functioning of the vestibular system. In contrast, later, different patterns of GVS, such as using a disruptive, unpredictable waveform, were employed to temporarily compromise the functioning of the vestibular system and help isolate specific sensory processes

(MacDougall et al., 2006). I applied disruptive GVS (dGVS) as a more targeted way of temporarily compromising the vestibular system than simply lying supine. I used this to investigate perceived time duration while the vestibular system was compromised.

Hypotheses

My thesis investigates the vestibular system's influence on time perception. I altered the activity of the vestibular system by changing body posture and by using disruptive galvanic stimulation. I hypothesize:

H1 There will be a difference in time estimation depending on body posture. I hypothesise that the perception of time, as measured by the perceived duration of stimuli in the modalities of vision, touch and hearing, will be slowed when vestibular activity is rendered less reliable while supine. That is, a stimulus will need to be on for longer to be judged as the same duration as when the participant is upright.

H2 The perceived duration of visual, tactile, and auditory stimuli will differ such that a shorter stimulus in sound will be judged as the same length as a longer stimulus perceived through hearing or touch.

H3 I hypothesize that any impact of posture on the perception of time (hypothesis 1) will also be found in the presence of disruptive galvanic vestibular stimulation.

Methods

Overview:

I tested my three hypotheses in four Experiments. Participants were asked to judge whether a stimulus was longer or shorter than their internal idea of one second. No feedback was provided. I used two randomly interleaved adaptive staircases (Quest) (Watson, 2017) to adjust the stimulus duration until the participants could no longer tell the stimulus duration from their internal idea of one second. Participants were tested while supine and upright. Visual perceived durations were also tested with and without disruptive Galvanic Vestibular Stimulation.

Participants

For my four Experiments, 124 participants (31 participants for the light Experiment, 34 for GVS, 28 for sound, and 31 for the touch Experiment) were recruited from the URPP of York University. During a strike (February 26, 2024-April 19, 2024), 12 participants were recruited from York University's graduate student population. All participants had normal or corrected-to-normal vision. York's Ethics Board approved all Experiments. All participants signed a written consent form.

Experiment 1: Light as stimulus:

A helmet with a protruding arm (length 34 cm from eye) and a red LED (diameter 4mm) mounted at the end (Figure 1) was used to ensure that the stimulus was always the same size and at the same position relative to the viewer regardless of posture. Participants always saw the light at the same distance with the same intensity. The light was powered through a digital-to-analog converter (USB-1208 FS, Measurement Computing Inc) and turned on for a duration controlled by an adaptive staircase (see below). Participants were asked to report verbally whether the light

had been on for more than one second or less. Each participant did the same test four times, alternating between supine on the bed and standing up with the starting posture counterbalanced between participants. When participants said whether the perceived duration was more or less than one second, the experimenter recorded their responses by right-clicking the computer mouse for durations greater than one second, and left-clicking for durations less than one second.

Figure 1: A helmet with an LED light mounted at the end of a rigid black stick. The blue box at the back is the digital-to-analog converter, which converts the digital signals from the computer to a voltage to power the LED.

Experiment 2: Sound as stimulus:

Thirty participants (different from those used in the other Experiments) did the auditory Experiment. Each participant wore headphones and heard a tone (200 HZ) played at 56 dB generated by a program similar to that used to control the LED. They reported whether the sound was on for longer or shorter than their internal idea of one second. They did the same task four times, twice supine and twice standing up. The responses were recorded on the computer.

Experiment 3: Touch as stimulus:

30 new participants were recruited. Two vibrators or tactors (C2 tactors, Engineering Acoustics, California, see Figure 2) were used. The tactors were 1.17” diameter and 0.30” thick. Only a small central cylinder (0.34”) within the tactor actually vibrated. The tactors were attached to the backs of the participants’ hands and secured with tape. When the program started, they felt a vibration (200 HZ) at a comfortable intensity and of the same duration on both hands and reported whether the vibration was on for more or less than one second. The responses were recorded on the QUEST program running on the computer to generate the next duration and for later analysis.

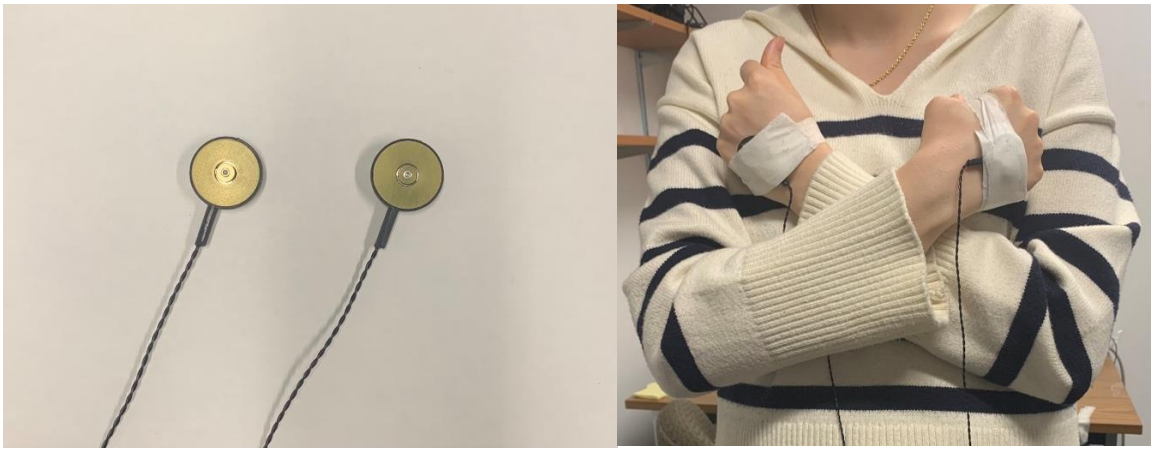

Figure 2: The left panel shows the vibrators (tactors), which were mounted on the backs of both participants' hands (right panel).

Experiment 4: Galvanic vestibular stimulation (GVS):

Thirty-three participants used the visual helmet apparatus (used in the first Experiment, Figure 1) with and without disruptive galvanic vestibular stimulation (dGVS) to see if it has the same effect on time perception as changing posture. The vestibular stimulation consisted of a

small current (50mA) applied through electrodes on the mastoid processes behind the ears. A reference electrode was placed in the center of the forehead. The electrodes were 3.25 cm diameter round carbon-conductor electrodes (9000 series electrodes; Empi et al., USA). A GVS system (Good Vibrations Inc.), generated the vestibular stimulus controlled by a PC. The vestibular stimulus was a sum-of-sines waveform with dominant frequencies at 0.16, 0.32, 0.43, and 0.61 Hz (maximum current limited to ±5 mA) which has been shown to reliably disrupt the vestibular system. (MacDougall et al., 2006; Moore et al., 2006).

Each participant was asked to sit on a chair and look at the LED. The GVS electrodes were placed on their bulla behind the ears (see Fig 3). For one data session, their GVS actively affected their vestibular system. They reported whether the LED was on for longer or shorter than one second. Then, the GVS electrodes were attached to their neck (a location that does not affect their vestibular system) to provide sham stimulation (since the electrical stimulation evokes a prickling sensation on the skin). The responses were recorded on the computer.

Figure 3: Participant experiencing dGVS. Looking at the LED while the GVS electrodes were on the skin over the bullae behind the ears.

Methodology

For each of the four Experiments, the stimulus duration was controlled by two randomly interleaved adaptive QUEST staircases where each stimulus value depended on the participant's previous response. One staircase started with a long time – much longer than I expected their estimate of 1s to be (1,7s) and the other a short time (0.3s). Participants were asked to report whether the stimulus was on for longer or shorter than one second, and the staircases honed in on the duration at which their judgments (longer or shorter) were random (i.e., the point at which they could not tell the difference between the presented stimulus and 1s). The staircase stopped after 20 trials. The data were then fit with a logistic psychometric function to obtain the point of subjective equality (PSE). For Experiments 1–3, participants were tested four times: twice while supine on a bed and twice while standing upright. For Experiment 4, dGVS was substituted for the supine condition, and sham neck stimulation was applied to the non-supine condition. The supine or dGVS condition was alternated with the standing or sham stimulation condition and which condition was tested first was counterbalanced across participants.

I used a Bayesian adaptive psychometric method known as a QUEST (Watson & Pelli, 1983). I ran two interleaved QUEST staircases with initial estimates of 1.7s and 0.3s, which I expected to bracket my subjects' estimates of the duration of 1s and an initial standard deviation of ±20s. The grain (step size) was set to 0.01s. The algorithm assumes the observer's psychometric function follows a Weibull distribution and adaptively determines the amount of distortion to be presented based on the participant's response to the previous trials. As the Experiment goes on, knowledge of the observer's psychometrics accumulates.

Data analysis

To visualize and confirm the QUESTs performance, the participant's decisions from the staircases (e.g., Fig 4) were plotted against the duration used for each trial (e.g., Fig 5) and fitted with a logistic (Equation 1) using the curve fitting toolbox in MATLAB.

$$\text{Decision} = 1/(1+\exp(-(x-x_0)/b)) \quad \text{(eq. 1)}$$

where x_0 is the PSE, x is the presented duration and b is an estimate of the function's slope. Each Quest staircase ran for 20 trials (40 trials total/condition) in each block of the four blocks. To assess differences in how participants reacted to the postural manipulation in the different modalities (i.e., the PSEs in each condition), I employed two-tailed t-tests to test my hypotheses. The dependent variable was the participants' responses in each trial.

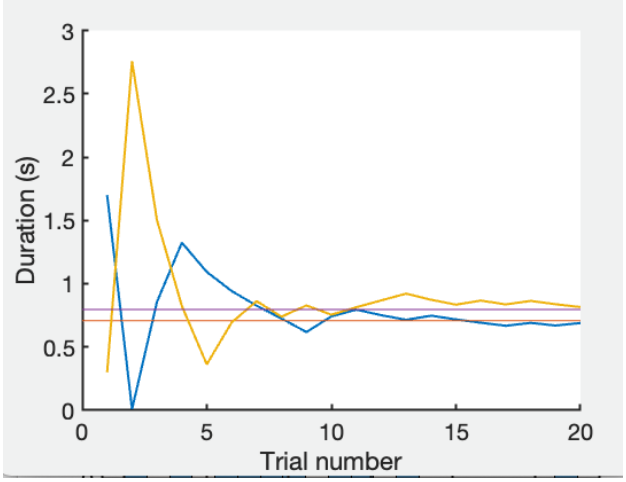

Figure 4: The duration of the stimulus (y-axis) tested is plotted as a function of trial number (x-axis). The two colors correspond to the two interleaved QUESTs (one starting way above 1s and the other starting below 1s). The two staircases converge on the actual perceived duration as trials progress.

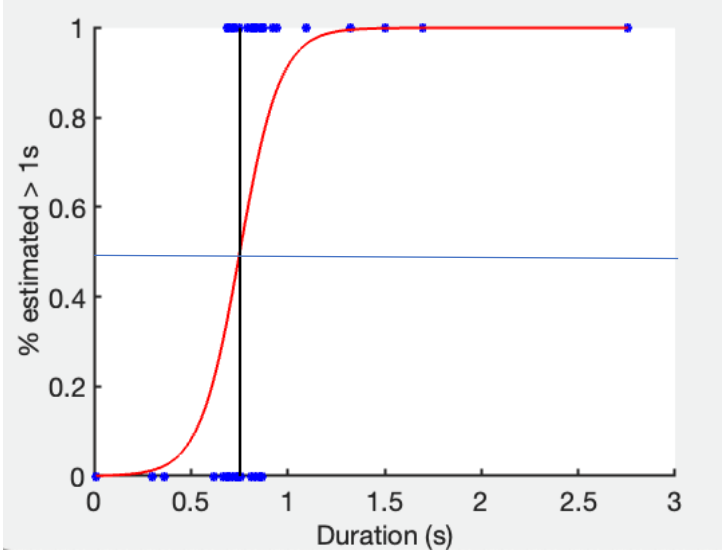

Figure 5: The y-axis indicates whether the participant said “longer” (1) or “shorter” (0) plotted as function of the stimulus duration (x-axis). The red line shows the best fit logistic function (eq1) plotted through the data. The black vertical line indicates the PSE where psychometric function crosses Y=0.5 (indicated by the horizontal blue line).

Results

Figure 6 summarizes the results for all four comparisons of the PSEs in each of the tested conditions. For the visual judgements, A one-tailed paired-samples t-test was used to assess whether time estimations were significantly longer in the supine posture compared to standing posture. There was a significant difference in the estimation of time duration between the supine posture and standing posture. A Bonferroni correction was not required as I was testing specific hypotheses (see Armstrong, 2014) *(M = 1.13, SD = .61)* vs. *M = 1.07, SD = .57); t(30) = .1.83, p = .038*. As predicted, time estimation for the duration of an LED differs depended on posture for visual stimuli. Participants underestimated the duration of one second when supine compared to when they were standing (that is they needed the light to be on for 60ms longer than when upright to be judged as one second). There was also a difference of 80 ms between visual duration estimations when people were stimulated with dGVS *(M = .89, SD=.41),* compared to the control condition (no GVS) *(M=.81, SD=.34*, *t(33) = 2.25, p = .015)*. There was no effect of posture on the perceived duration of the sound or tactile stimuli. All data were included in the analyses except for the responses from the experimenters.

Table 1 summarizes the mean durations perceived as equal to the participants' internal idea of 1s, along with the means and variances. Table 2 indicates means and variances of the differences between comparisons. Tables 3 report the statistical comparisons of postures for vision (light), sound, and touch, and dGVS for visual stimulus.

Descriptives

	N	Mean	Median	SD	SE
Light-supine	31	1.132	0.996	0.614	0.1103
Light-upright	31	1.068	0.951	0.570	0.1024
Sound-supine	28	0.771	0.754	0.360	0.0679
Sound-upright	28	0.781	0.756	0.399	0.0755
Touch-supine	31	1.062	1.047	0.336	0.0604
Touch-upright	31	1.061	1.115	0.324	0.0583
GVS	34	0.899	0.843	0.411	0.0705
Sham	34	0.819	0.777	0.347	0.0595

Table 1: Descriptive results of all the data in all conditions. All numbers in seconds.

Paired Samples T-Test

			statistic	df	p	Mean difference	SE difference		Effect Size
Light-supine	Light-upright	Student's t	1.8340	30.0	0.038	0.06463	0.0352	Cohen's d	0.32939
Sound-supine	Sound-upright	Student's t	−0.4090	27.0	0.657	−0.01002	0.0245	Cohen's d	−0.07730
Touch-supine	Touch-upright	Student's t	0.0493	30.0	0.480	0.00160	0.0324	Cohen's d	0.00886
GVS	Sham	Student's t	2.2546	33.0	0.015	0.08029	0.0356	Cohen's d	0.38665

Note. H_a $\mu_{\text{Measure 1 - Measure 2}} > 0$

Table 2 indicates means and variances of the differences between comparisons.

Paired Samples T-Test

			statistic	df	p
Light-supine	Light-upright	Student's t	1.8340	30.0	0.038
Sound-supine	Sound-upright	Student's t	−0.4090	27.0	0.657
Touch-supine	Touch-upright	Student's t	0.0493	30.0	0.480
GVS	Sham	Student's t	2.2546	33.0	0.015

Note. H_a $\mu_{\text{Measure 1 - Measure 2}} > 0$

Table 3: The t-test results comparing upright and supine for all stimuli

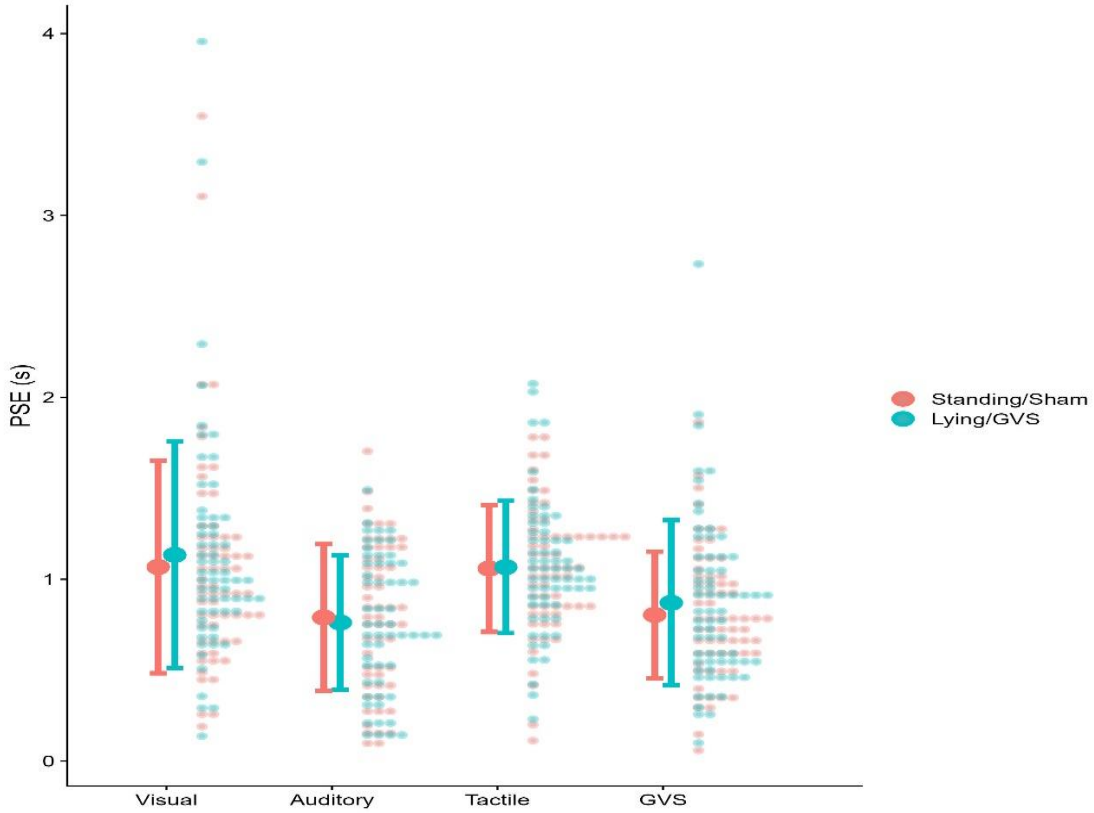

Figure 6: The stimulus condition is indicated on the x-axis and the PSEs on the y-axis. The big circles are the mean PSE across all participants, and the lines are +/- 1 standard deviation. The dots are each participant's individual PSE. For visual, auditory and tactile, green is with participants lying, red is with participants standing. For the dGVS data green is with the stimulation and red is with the sham stimulation.

Discussion

My study measured the vestibular system's influence on duration perception. My results showed that both changes in posture and disruptive vestibular stimulation (dGVS) alter the perception of duration of a visual stimulus. I further evaluated whether the vestibular system's influence on the perceived duration of stimuli was consistent across different sensory modalities. Only the duration of a visual stimulus was affected. The perceived duration of a visual stimulus was longer when supine (by 45ms) or in the presence of dGVS (by 66ms) compared to when upright or with sham stimulation. However, posture change did not affect the perceived duration of auditory or tactile events. In addition, my second hypothesis was confirmed as the duration perception assessed through different sensory modalities differed. A "visual second" (0.99s) and a "tactile second" (1.0s) were perceived as the same duration as an "auditory second" even though the auditory stimulus was, in reality, much shorter (0.75s). I will discuss possible reasons for each observation here.

Differences between the senses:

The stimulus-dependent estimation of duration in my study may appear at first glance to be inconsistent with the findings of Wearden et al. (2006), in which participants overestimated the duration of periods marked using auditory markers compared to when the period was delineated by visual markers. In my study, participants matched a shorter duration sound as being equal to a light of a longer duration. The differences in these results may stem from the different experimental designs used in the two studies. In my study, participants judged the perceived duration of a continuous stimulus—either a sound or a light—whereas Wearden et al used auditory or visual stimuli only as temporal markers to indicate the start and end of a time

interval. Using a stimulus to mark time boundaries is fundamentally different from perceiving the duration of the stimulus itself. In other words, using a sound or light as a temporal delineator is not equivalent to experiencing its duration.

A possible reason for perceiving the duration of stimuli presented through different sensory channels differently could be differences in the intensity of the visual, auditory and tactile stimuli as suggested by Toso et al. (2021). They showed that higher stimulus intensities resulted in shorter time judgments, likely due to increased arousal and attentional processing. In our study, we kept intensity consistent across each condition from start to finish, but we made the stimuli only approximately equal intensity and did not attempt to match them crossmodally in the manner of Spence (2011) or explore the effect of changes in intensity across modality. Future Experiments should vary the intensity of each stimulus to see if intensities could be found in which the perceived duration of a sound was the same as the perceived duration of a light, for instance.

Effect of vestibular stimulation

Changing posture altered the perceived duration estimation for visual stimuli. Participants overestimated one-second intervals when supine compared to standing and also under disruptive galvanic vestibular stimulation (dGVS). Research by Ren et al. (2025) indicated a tendency to overestimate time durations after 30 min of −30° head-down tilts (HDTs). They measured the time estimations of participants before and after 30 min of −30° HDT. Their results showed that participants overestimated the duration of time intervals after being in HDT for half an hour. Their results for the HTD condition are similar to my supine condition and their results the after-HTD could be taken as equivalent to my standing condition. Their reasoning for their

observation was that, based on the internal clock model commonly used to explain interval timing perception, a pacemaker, a switch, and an accumulator are involved in duration perception. The pacemaker generates pulses relatively constantly, though arousal levels can influence this rate (Droit-Volet et al., 2004). Increased arousal can accelerate the clock's pulse rate, accumulating more pulses and leading to a time overestimation. Ren et al. (2025) suggest that in their -30° HDT condition, physiological changes such as reduced pulmonary ventilation, lower lung capacity, and elevated intracranial pressure may have increased arousal, potentially contributing to the time overestimation observed in this study. However, any explanation of this type based on physiological changes related to change in posture cannot explain my data because if such changes caused the changes in the perceived duration of a light we would expect them to also alter time judgments for all of my conditions: light, sound and touch whereas I observed only changes in duration estimations for vision and not for touches or sounds.

One possible reason for the changes I observed specifically in visual/vestibular interactions in the perception of duration is that the vestibular system is more tightly integrated with the visual system than it is with the auditory or tactile systems. For instance, peripheral vision is highly sensitive to motion and plays a key role in maintaining balance and perceiving self-motion (Grace Gaerlan et al., 2012) and optic flow is essential for accurate perception of heading and distance perception during self-motion (Horrocks et al., 2022). This strong interaction between visual and vestibular cues helps explain why visual time perception may be more affected by vestibular disruption. In contrast, auditory and tactile inputs are less directly involved in self-motion perception. For example, while an earth-stationary sound source can indicate self-motion sounds are more often emitted from moving objects and therefore do not provide a clear unambiguous signal about one's own movement through space. Similarly,

stimulating the vestibular system through galvanic vestibular stimulation (GVS) can create a sensation of movement, and simply looking at a visually rich environment can evoke Vection—a compelling sense of self-motion (Howard & Howard, 1994). Murovec et al. (2021) confirmed that visual stimuli are most strongly associated with vection, whereas auditory and tactile inputs contribute to a lesser extent. This could explain why visual time perception is more susceptible to vestibular influence than auditory or tactile time perception.

Ren et al. (2025) refer to the state-dependent network, a theoretical model in which time perception is modulated by dynamic neural states influenced by sensory inputs and physiological conditions (Buonomano & Maass, 2009) such as head-down bed rest (Ravichandran-Schmidt & Hass, 2023). When considering the effect of head-down bed rest, a posture often used to stimulate vestibular unloading in perceptual research Ren et al. (2025) proposed that changes in body orientation may alter the neural network's state, thereby affecting time perception-particularly for shorter intervals. This aligns with the current study's findings, where supine posture and vestibular conditions indeed influenced duration estimations. However, it remains unexplained why only stimuli perceived through the visual sense would be affected.

Navarro Morales et al. (2023) observed that astronauts in weightless conditions tended to overestimate the duration of one minute, comparable to the overestimation I observed when estimating one-second intervals when supine or during dGVS. They suggested that the absence of static otolith signals in weightlessness may contribute to an acceleration of the internal clock but again it is not clear why only visual durations would be affected following such a central change.

Conclusion:

My findings show that posture and dGVS influence time perception specifically when using visual stimuli, while the perception of auditory and tactile durations remain unaffected. This suggests that the vestibular system selectively modulates time perception in a modality-dependent manner, with a particular influence on visual processing. This challenges the idea of a universal internal clock and suggests that specific interactions between sensory systems shape time perception.

My findings have important implications for our understanding of perception in real-world scenarios where posture, motion, and multisensory integration are critical. That visual time perception is modulated by vestibular input suggests that our experience of time is not fixed, but context-dependent—altered by changes in bodily orientation and motion. This has potential consequences in environments where accurate timing is essential.

For example, in **virtual reality** and **augmented environments**, where visual-vestibular congruence is often disrupted, users may experience subtle shifts in time perception that could impact realism, immersion, or task performance. In **spaceflight**, where the vestibular system is challenged by the absence of gravity, astronauts may be especially prone to altered visual timing, which could influence coordination and decision-making under time pressure.

In **clinical rehabilitation**, particularly in patients with vestibular dysfunctions or balance disorders, altered visual time perception could interfere with spatial orientation and motor planning. Rehabilitation protocols might benefit from accounting for these sensory-timing interactions, for example by tailoring visual feedback or balance tasks to recalibrate temporal perception.

There are also potential **safety implications**. Since vestibular stimulation during motion (e.g., in vehicles or aircraft) can subtly shift visual time perception, individuals might misjudge speed or timing—such as the duration of gaps in traffic or the timing of an approaching obstacle—especially in high-stakes contexts like **driving**, **piloting**, or **sports**. This opens up a promising avenue for research into how vestibular influences on time perception affect real-time decision-making and how interventions might mitigate risk in dynamic environments.

Limitations:

My study only compared upright and supine postures. This binary comparison may not capture the full postural influence on vestibular processing and time perception. Future studies might look at intermediate or dynamic postures (e.g., leaning, or motion, either real or simulated). Individual differences in **vestibular sensitivity, sensory integration, or time estimation ability** might have also introduced variability that could affect the results. A larger sample is recommended to look at such sources of variability. We only examined a one-second duration which may not be generalizable to other time spans. However, my research offers an interesting new perspective for future research in this field.

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